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The Simulation of Stresses Distribution and Fatigue Life of Crack Initiation of Gas Pipelines

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Abstract: This paper presents the simulation of stresses distribution and crack initiation of gas pipelines surface. The materials are used from low carbon steel with artificial defects under external load. A finite element analysis (FEA) is used to investigate the highest Von Mises stress and fatigue life shows that crack initiation occurs on the pipeline surface. The parameter is used as the difference loads from 60 kN to 120 kN have been used to investigate the maximum stresses. In this research the maximum stresses occurred at corner gauge of joint of two pipelines. The stress distribution analysis from the model developed was successfully simulated and the critical and potential area for fatigue life of crack initiation, this performance result is compared with previous researcher.

Keywords: Stress Distribution, Crack Initiation, Gas Pipeline, Linear Elastic, Mechanical Properties, Loading, FEA, and Fatigue Life.

INTRODUCTION

Nowadays, there is many damages are happened on gas pipeline surface effect by external loading and fluid pressure inside pipe. The failure of gas pipeline that was risk for human life, due to gas distribution from the petroleum field close the people living area. The researcher have been performed analysis results to avoid the failure occurred on gas pipeline surface.

Fatigue crack growth can be defined as the weakening or breakdown of a material subjected to cyclic stresses. These stresses can be due to a variation in loads or temperature (Belylschko, 2009). In particular linear fracture mechanics assumes a material is linear elastic and isotropic. This is despite the longitudinal crack being deemed to be more critical than a circumferential crack since the longitudinal crack is associated with bursting and circumferential crack leads to leaking (Alhussein et al., 2013).

That formed around non-metallic inclusions and later cracks grew from corrosion pits that formed randomly on the surface (Y.Z. Wang et al, 1998 & Y.Z. Wang et al, 1999), and some cracks induced by corrosion pits were related to stress cells caused by the difference of residual stress level over a much large area (G. Van Boven, 2007). These pits may act as stress raisers to initiate cracks. Cracks can also be nucleated around other types of pits associated with metallurgical discontinuities. Wang et. Al., (2000) indicated that some corrosion pits can be formed preferentially along the heavily deformed metal in scratches on the surface.

Crack initiation plane orientation and fatigue initiation life prediction are based on the proposed model. A three-dimensional (3D) finite element model (FEM) for the pipe/surface inner flow joint analysis is developed with the use of the sub-modeling technique to achieve both computation efficiency and accuracy (Schutz, 1996). The stress response of the numerical simulation of the pipe inner flow motion is used for fatigue life prediction (Colombo, et al, 2006; Fraternali, 2007).

METHODOLOGY

Finite element analysis code (ANSYS 11.0) to simulate the stress distribution and crack initiation of gas pipeline. The loading analysis showed the emergence of an out-of-phase rotation of principal stress over time that made the prediction of the position and direction of crack initiation was difficult. The uniaxial stresses amplitude was replaced by a measurement of the amplitude of equivalent stresses (von Mises), the equation of which can be written as:

$$\frac{1}{2}\left\{\left(\Delta\sigma_1-\Delta\sigma_2\right)^2+\left(\Delta\sigma_2-\Delta\sigma_3\right)^2+\left(\Delta\sigma_3-\Delta\sigma_1\right)^2\right\}^{\frac{1}{2}}+\mathrm{A}\left(\overline{\sigma_1}+\overline{\sigma_2}+\overline{\sigma}_3\right)=C$$

Where $\Delta\sigma_1$, $\Delta\sigma_2$, and $\Delta\sigma_3$ are amplitudes of the principal stresses; $\overline{\sigma}_1$, $\overline{\sigma}_2$, and $\overline{\sigma}_3$ are mean values over a cycle of the principal stresses; and b and c are material constants.

In plastic shakedown and material response, the Smith–Watson–Topper parameter was used after the following modification in the multi-axial proportional and none proportional loading for materials with cracks, in accordance to Model I, only the stress occurring in critical plane is considered and is written as follows:

$$\sigma_{n,\max}\frac{\Delta\varepsilon_1}{2}=\frac{\sigma'^2_f}{E}\left(2N_f\right)^{2b}+\sigma'_f\varepsilon'_f\left(2N_f\right)^{b+c}$$

where σn,max is the maximum normal stress in the plane with normal n; σ'_f and ε'_f represent the fatigue strength and fatigue ductility coefficients, respectively; E is Young's

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modulus; b and c are the fatigue strength and fatigue ductility exponents, respectively; and N_f is the number of cycles to failure.

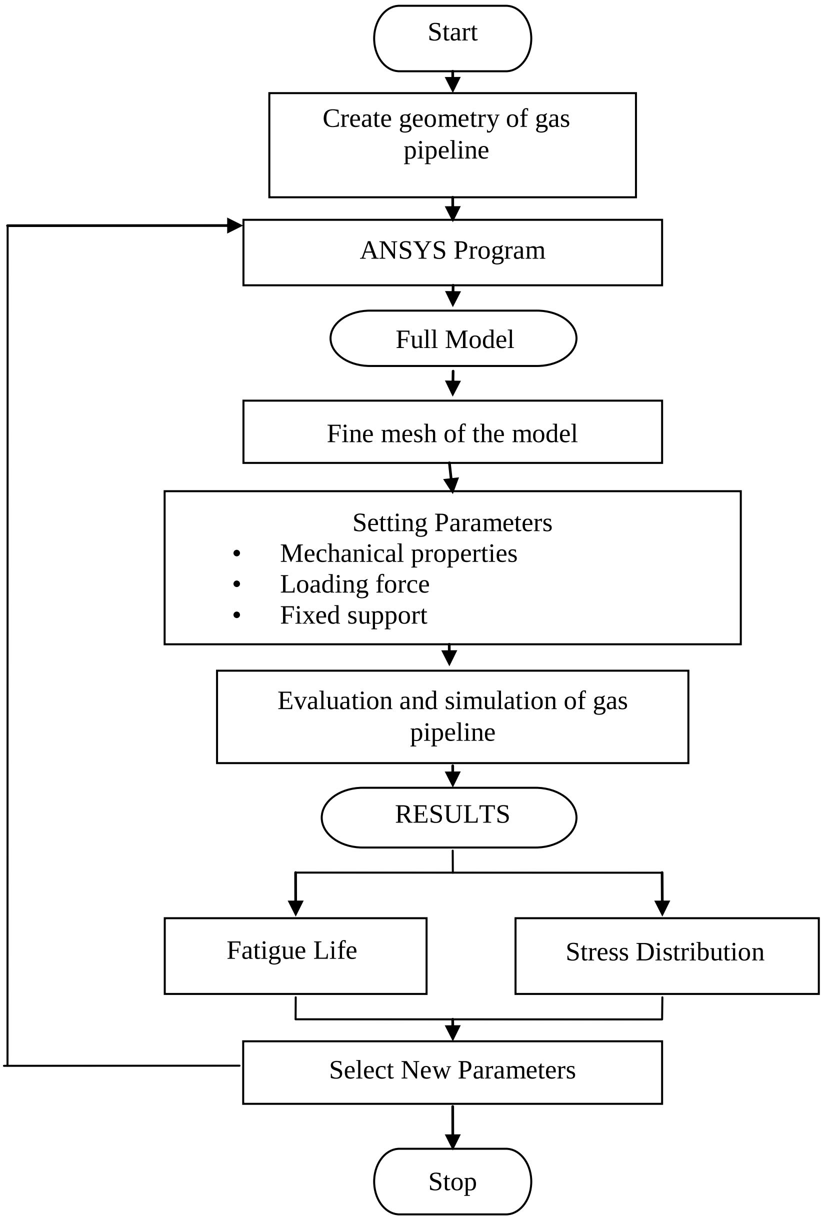
The simulation was operated in one direction using FEA under cyclic loading of external load on pipeline. The flow chart describes the processes of the simulation and modelling using FEA program code ANSYS to calculate the fatigue damage initiation life and stress distribution of gas pipeline surface at the joint area these cracks initiated at the joint and surface after several cyclic loadings (Anderson, 2005). The fatigue damage tolerance investigation is defined in the following equation:

$$FP = \left(\sigma^{\max}\right)\frac{\Delta\varepsilon}{2} + J\Delta\tau\Delta\gamma$$

where $\sigma_{\max}$ the maximum stress is normal to the crack plane, the constant J, Δε is the strain range normal to the crack plane, Δτ is the shear stress range on the crack plane,Δγ is the shear strain range on the crack plane, and $FP_{\max}$ is the fatigue parameter value, defined as the crack plane. The load chosen at the joint and corner gauge of gas pipeline effected from loading force location. The crack initiation of fatigue life created the following equation for the crack plane:

$$FP\max = \left(\left\langle\sigma^{\max}\right\rangle\frac{\Delta\varepsilon}{2} + J\Delta\tau\Delta\gamma\right)_{\max}\frac{(\sigma')^2}{E}\left(2N_f\right)^{2b} + \sigma'_f\,\varepsilon'_f\left(2N_f\right)b + c$$

Figure 1. Flow chart of simulation and modelling of pipeline model



The model for predicting the time to fatigue crack initiation life was calculated to know the number of cycles of fatigue life and is represented by the following:

$$N_f = \varepsilon_c / \Delta\varepsilon_r$$

Where ε_C is the constant determined by experiments, and $\Delta\varepsilon_r$ is the equivalent ratcheting strain per cycle.

The load is applied to the force on the surface of the pipe at joint region. Therefore, it was used to investigate the crack initiation life corresponding to the material response elucidated through FEA. The flow chart describes the simulation of the gas pipelines joint of 3D model using FEA code ANSYS 11.0, as shown in Figure 1.

ANSYS software is a general purpose finite element modelling package for numerically solving a wide variety of mechanical problems. Figure 2 shows the creation the 3D solid model of gas pipeline to simulate the stress distribution and crack initiation. The global mesh referring to the fine mesh at the locality of the crack tips by using FEA.

The enhancement of mesh quality is indispensable to all mesh generation algorithms, because the shape of the triangles generated directly is not always optimal. This is particularly, for a strongly graded mesh with element sizes varying rapidly, to improve the shape of the elements, at the final stage of the mesh generation as shown Figure 3.

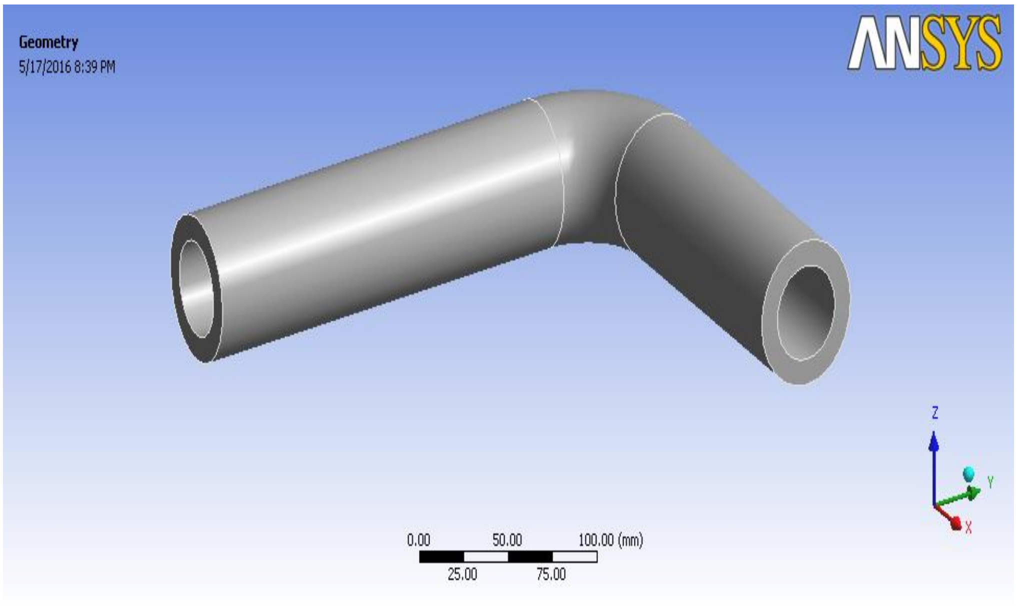


Figure 2. Solid model of gas pipeline

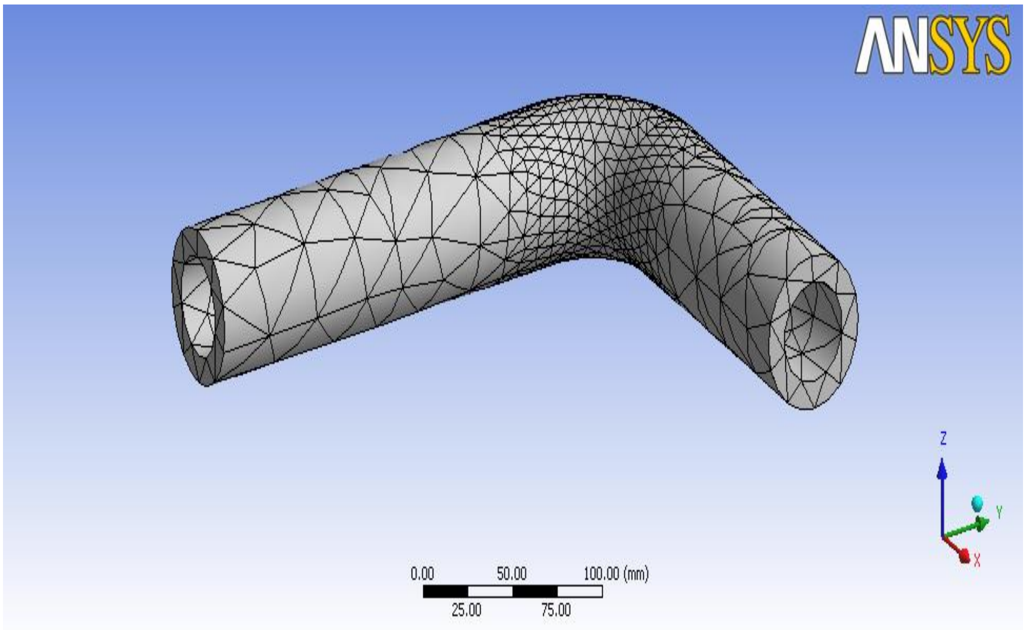


Figure 3. Mesh model of gas pipeline

RESULTS AND DISCUSSION

Figure 4 shows the results indicate that the maximum equivalent stress is found to be 592 MPa. This value is much higher than the yield stress determined in the tensile test. It is shown that the repeated loads on the same region induce plastic deformation on localized area and damage the gas pipeline surface. The area of high stress and crack initiation are effected from external loading and pressure determined by using FEA.

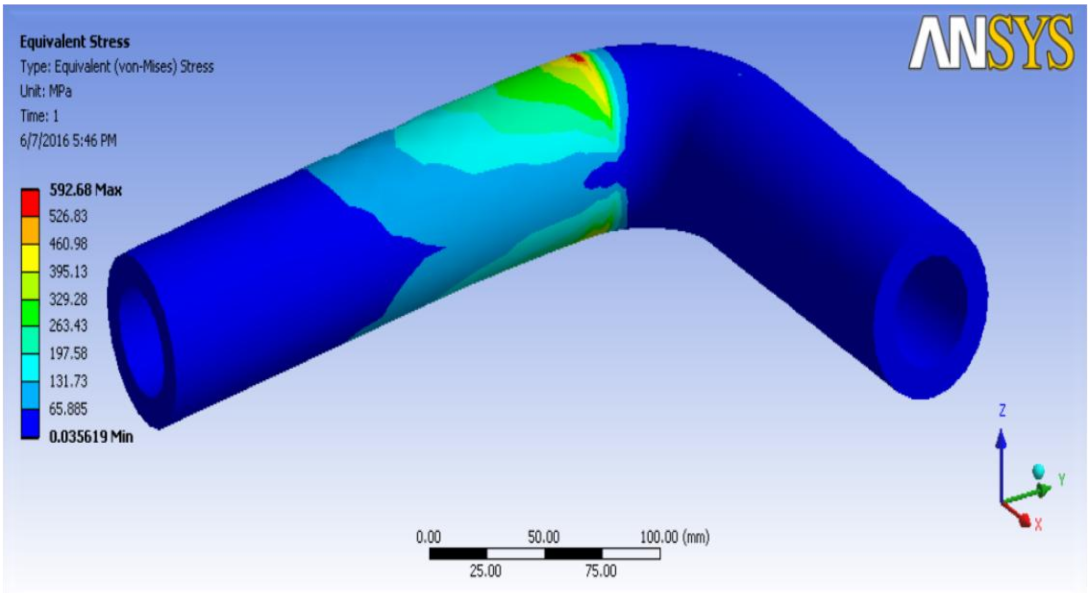


Figure 4. Highest stress distribution of gas pipeline

The high joint stress amplitude obtained at this location is consistent, the figure shows that the highest location of fatigue life was concentrated on the surface close to the corner region of gas pipeline as shown in Figure 5.

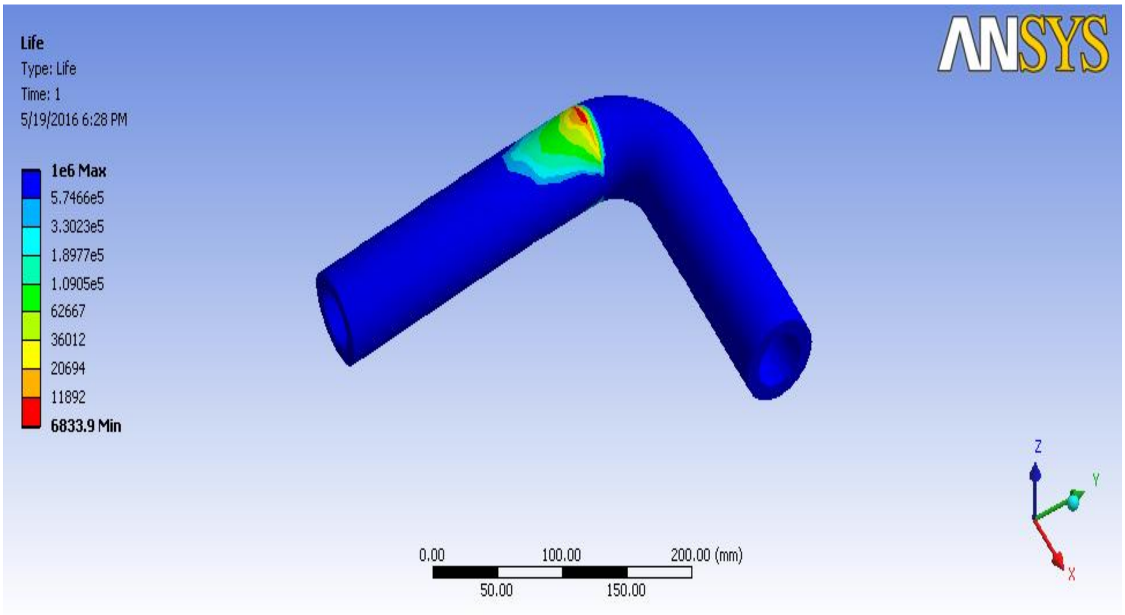


Figure 5. Fatigue life of gas pipeline

The stress distribution analysis result showed that the maximum equivalent stress resulted from the effected loading force as summarized in Figure 6. This values are higher than the yield and ultimate tensile of carbon steel gas pipeline. The analysis results give an indication that the corner gauge area of pipe will be deformed permanently with fracture and can't be safely used even at the highest maximum external load on the gas pipeline. Fatigue life of gas pipeline is long life before effected from external load, due to highest stresses at pipeline surface as shown in Figure 7. Therefore, noted that these results were obtained by assuming that the pipe is perfect without inherent defect in the material or that caused by welding or manufacturing processes.

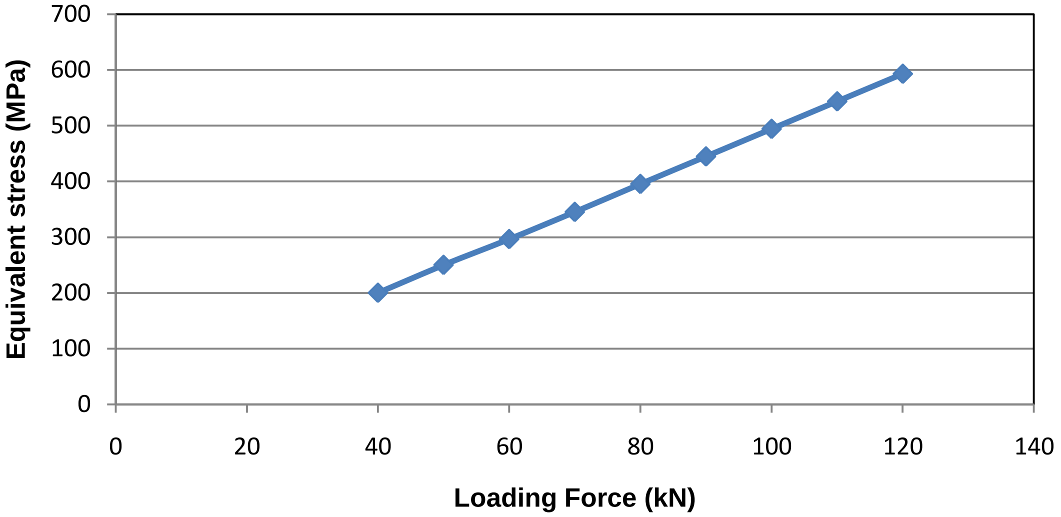


Figure 6. The equivalent stress with loading force on gas pipeline

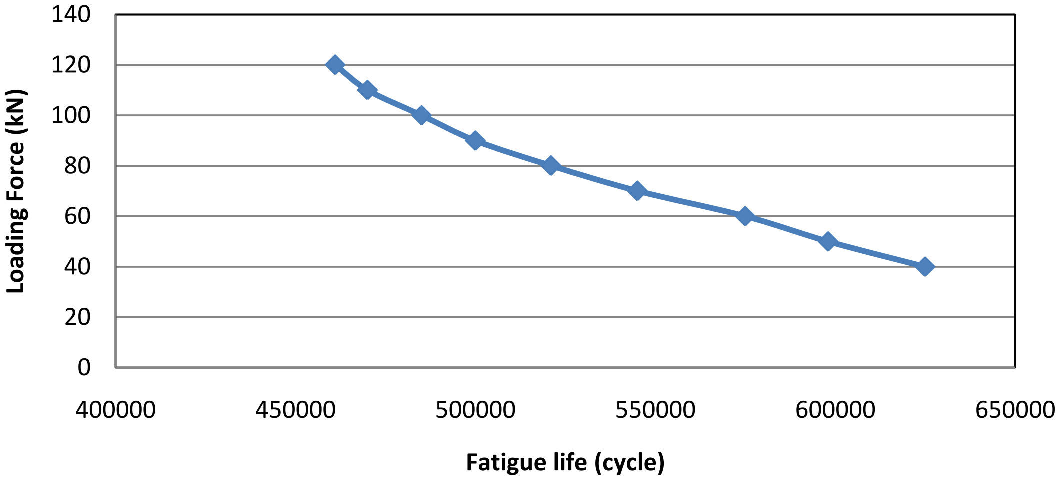


Figure 7. Fatigue life of gas pipeline

CONCLUSION

The damages and the stress distribution at the gas pipeline surface have been successfully investigated. The position of maximum Von mises stresses obtained by FEA shows the cracks initiated on the gas pipeline surface. The maximum value of fatigue crack initiation life was determined at 6500,000 cycles. The maximum stress distribution and crack initiation occurs at the corner region is motivated towards the running direction of the gas pipeline.

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